Hyperspectral OLR Retrieval Towards OLR Climate Data Record Production

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Acknowledgment

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- *NOAA CLASS Data Center*
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- *Thank Shi-Keng Yang (Sky) for discussions and review.*

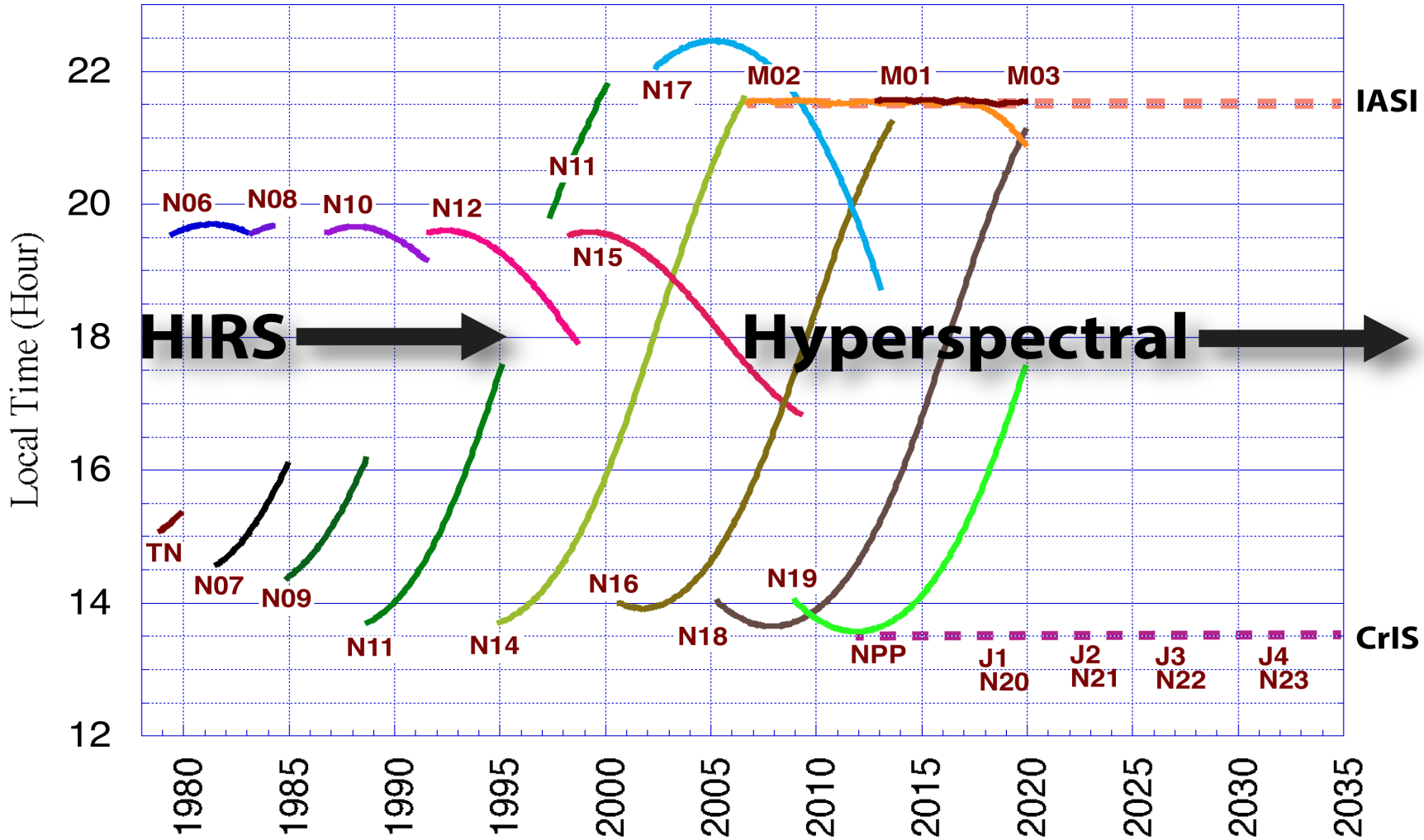
Outline

- Background
- Theoretical Basis
- Comparison of OLR Products
- Summary

Background

- NOAA/UMD OLR Climate Data Record (CDR)
  - HIRS OLR retrieval (primary), blended with Geo Imager OLR
  - 1979-Present, Global
  - 1° Daily and 2.5° Monthly
- Currently functional HIRS on NOAA-18,19 and Metop-A/M2,B/M1
  - *The last HIRS* is on Metop-B (since 2013)
- OLR CDR to be extended with OLR retrieved from operational hyperspectral sounder observations, supplementing/replacing HIRS
  - (09:30) Metop **IASI** (Infrared Atmospheric Sounding Interferometer)
  - (13:30) JPSS **CrIS** (Cross-track Infrared Sounder)

Equator Crossing Time for NOAA, MetOp & JPSS Polar Orbiters



Theoretical Basis

Spectral OLR Model Principles

- **Broadband:** Broadband radiance observations and Angular Distribution Model (**ADM**)

$$OLR = \frac{\int I_\nu(z_t;\theta,\phi)\,d\nu}{ADM(angles, scene, cloud, T, q, \ldots)}$$

- **Spectral:** Spectral radiance observations and Spectral Angular Model (**SAM**)

$$OLR = \int F_\nu \, d\nu$$

$$F_\nu = \int_0^{2\pi}\int_0^{\pi/2} I_\nu(z_t;\theta,\phi)\cos\theta\sin\theta\,d\theta\,d\phi = SAM(I_{\nu_x}(\theta),\theta)$$

- **Spectral flux estimation principles**:
  1. ***Inter-Frequency Correlations*** *- Radiances at one frequency strongly correlate with radiances at another frequency with similar absorption features.*
  2. ***Intra-Frequency/Angle Correlations***
     - *Using absorption strengths to surrogate optical path lengths*
     - *Spectral flux integration can be estimated with radiances at selected angles (Gaussian quadrature)*

- **Previous works**: Total LW spectrum reconstruction from IASI observations *– Lee, Ellingson & Gruber (2010); Turner, Lee & Tett (2015)*

IASI OLR Model

IASI OLR Model is a 3-predictor multiple linear regression model in quadratic forms.

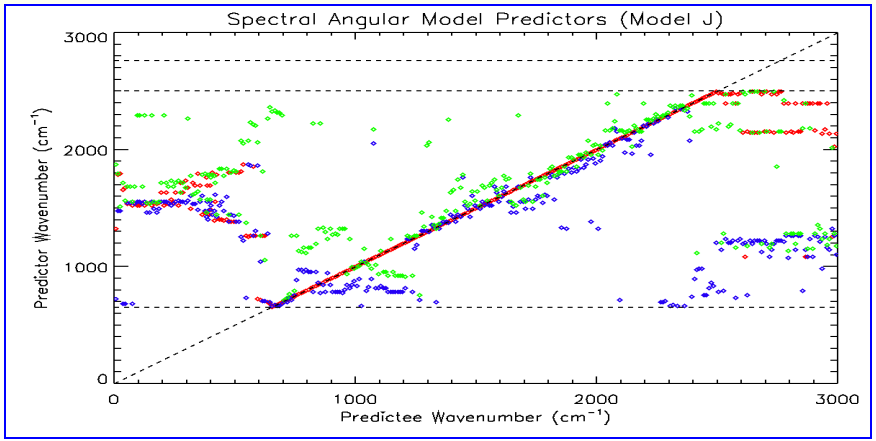
Predictors are natural log of IASI radiances aggregated to 10 cm^{-1} intervals in 650-2500 cm^{-1}. (2500-2760 cm^{-1} radiance observations not used to avoid solar contamination.)

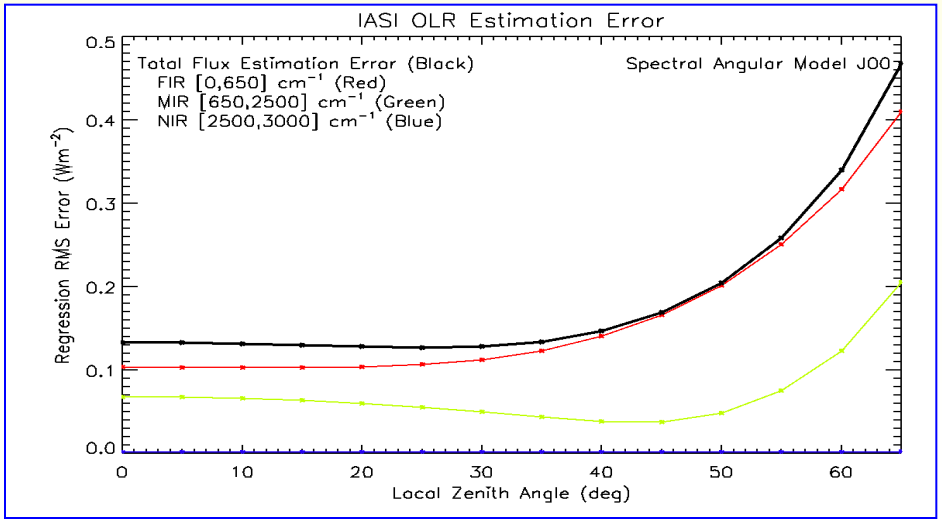
$$OLR = \int F_\nu d\nu$$

$$\log(F_\nu) = a_0(\theta) + a_1(\theta)x_1(\theta) + a_2(\theta)x_2(\theta) + a_3(\theta)x_3(\theta) + a_4(\theta)x_1^2(\theta) + a_5(\theta)x_2^2(\theta) + a_6(\theta)x_3^2(\theta)$$

$$x_\nu(\theta) = \log(I_\nu(\theta))$$

*RMS regression errors for **Total OLR** estimation range from **0.13 - 0.47 Wm^{-2}**, dominated by "FIR" spectral flux estimation errors.*





Comparisons of OLR Products

Assessing Retrieval Accuracies at Instantaneous Foot-print Level

- *Mean OLR Diff – Relative Bias*
- *StdDev OLR Diff – Random errors (Precision)*

Data

Temporal: Jan, Apr, Jul & Oct, 2018

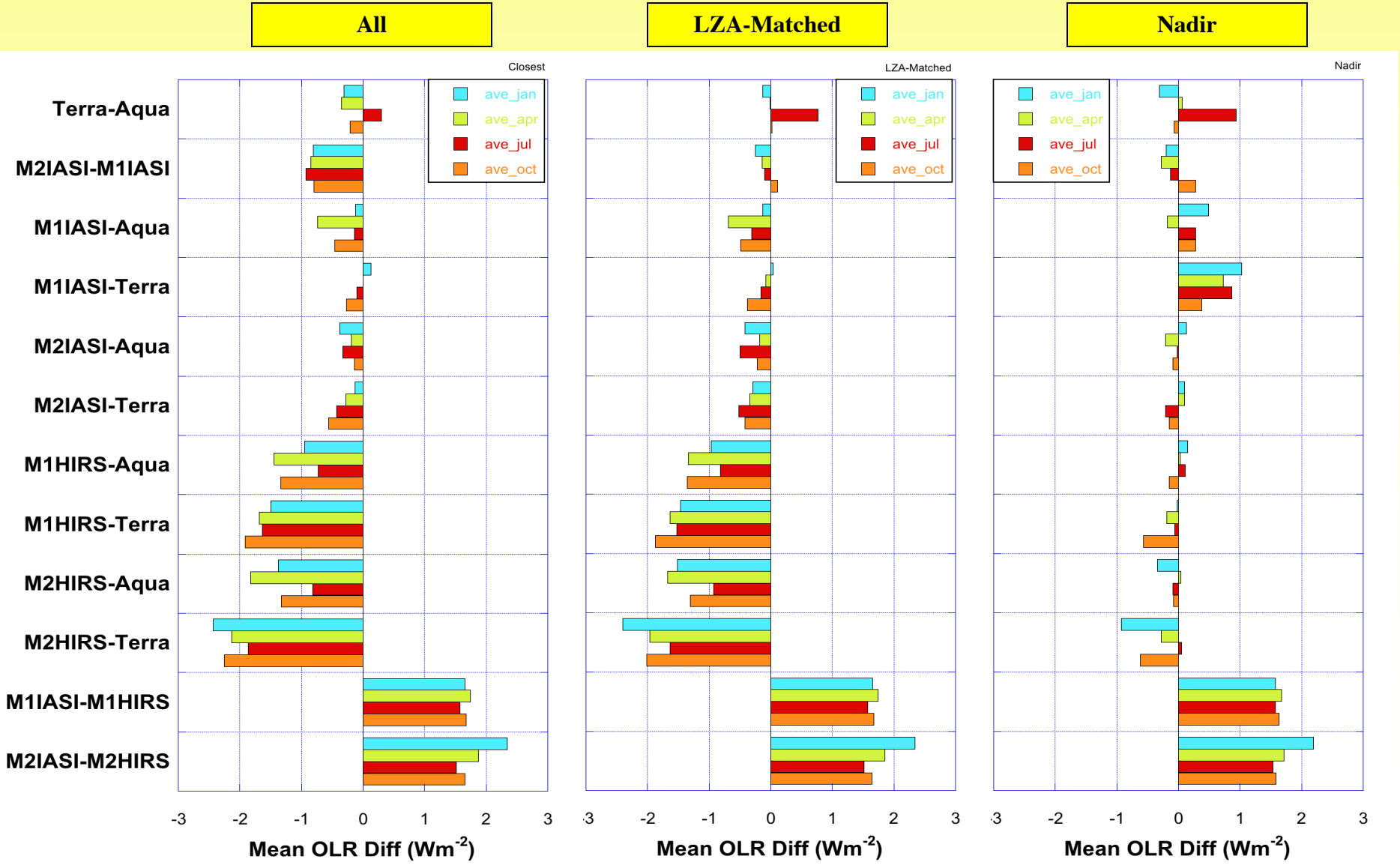
Instrument	Platform	Product	Ver.	Source
CERES	Terra Aqua	SSF OLR	XTRK Ed4a	LaRC/NASA
IASI	MetOp-A/02 MetOp-B/01	Level 1C		CLASS/NOAA
		OLR	Ver. 0.1	CISESS/UMD
HIRS	NOAA-18 NOAA-19 MetOp-A/02 MetOp-B/01	Level 1B		CLASS/NOAA
		OLR	Ver. 2.7	CISESS/UMD

Collocation and Processing

- Collocation: closest and within 0.5° to reference target FOV, regardless observing angle, within ±60 minutes
  - LZA-Matched = |dLZA| < 5°
  - Nadir = |LZA| < 10°
- Daytime: 6:00-18:00 local time
- ***"Homogeneity"*** metrics: STD of OLR in 1° circle encompassing target

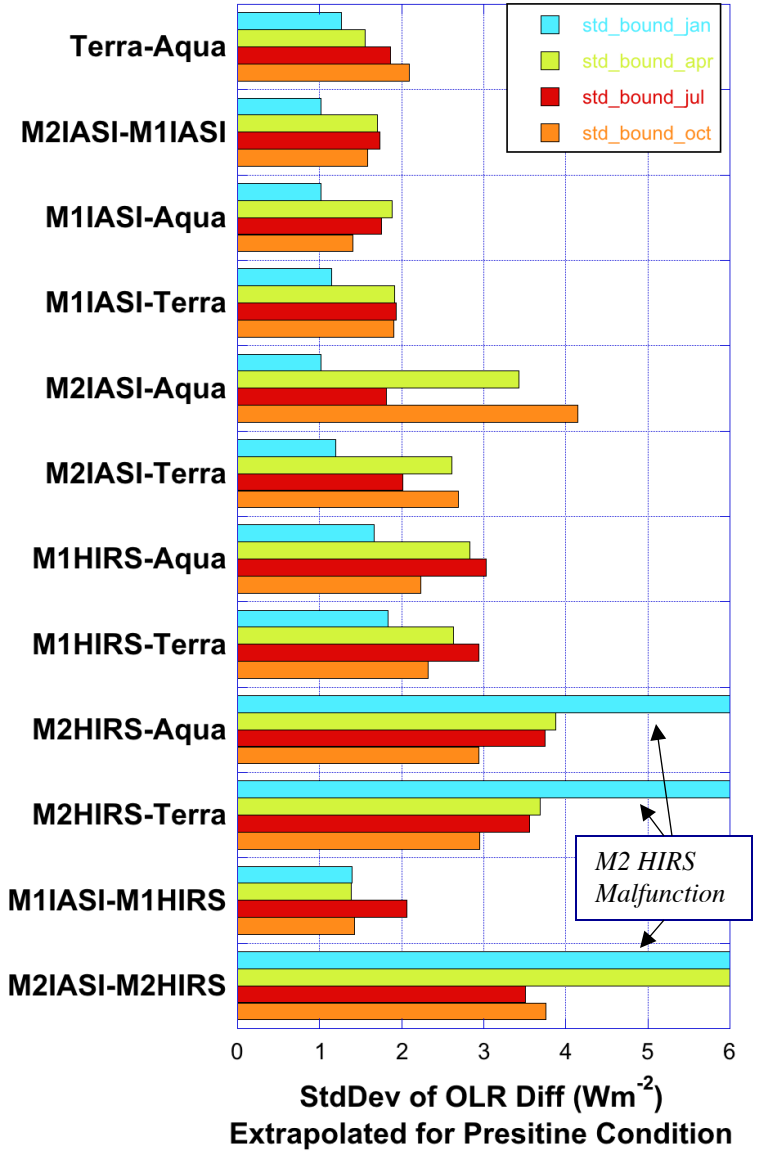
Mean OLR Diff

- *All collocated data*
- *LZA-matched*
- *Nadir*

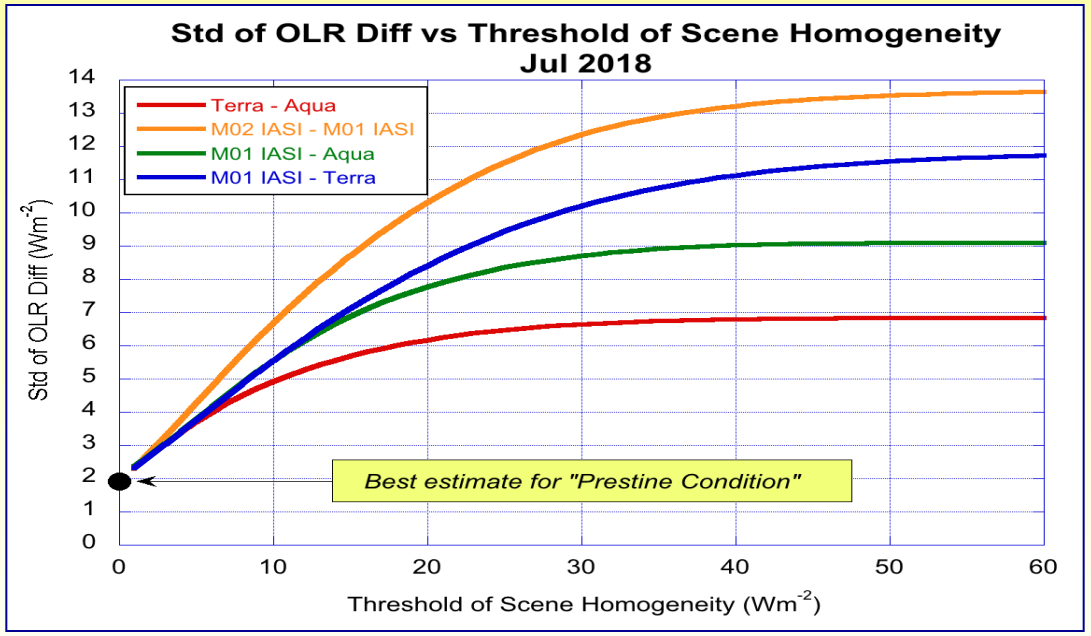

All
LZA-Matched
Nadir
Closest
LZA-Matched
Nadir
ave_jan
ave_apr
ave_jul
ave_oct
Terra-Aqua
M2IASI-M1IASI
M1IASI-Aqua
M1IASI-Terra
M2IASI-Aqua
M2IASI-Terra
M1HIRS-Aqua
M1HIRS-Terra
M2HIRS-Aqua
M2HIRS-Terra
M1IASI-M1HIRS
M2IASI-M2HIRS
-3
-2
-1
0
1
2
3
Mean OLR Diff (Wm-2)

Best Estimate of Precision at "Pristine Conditions"

Reducing Sampling Errors



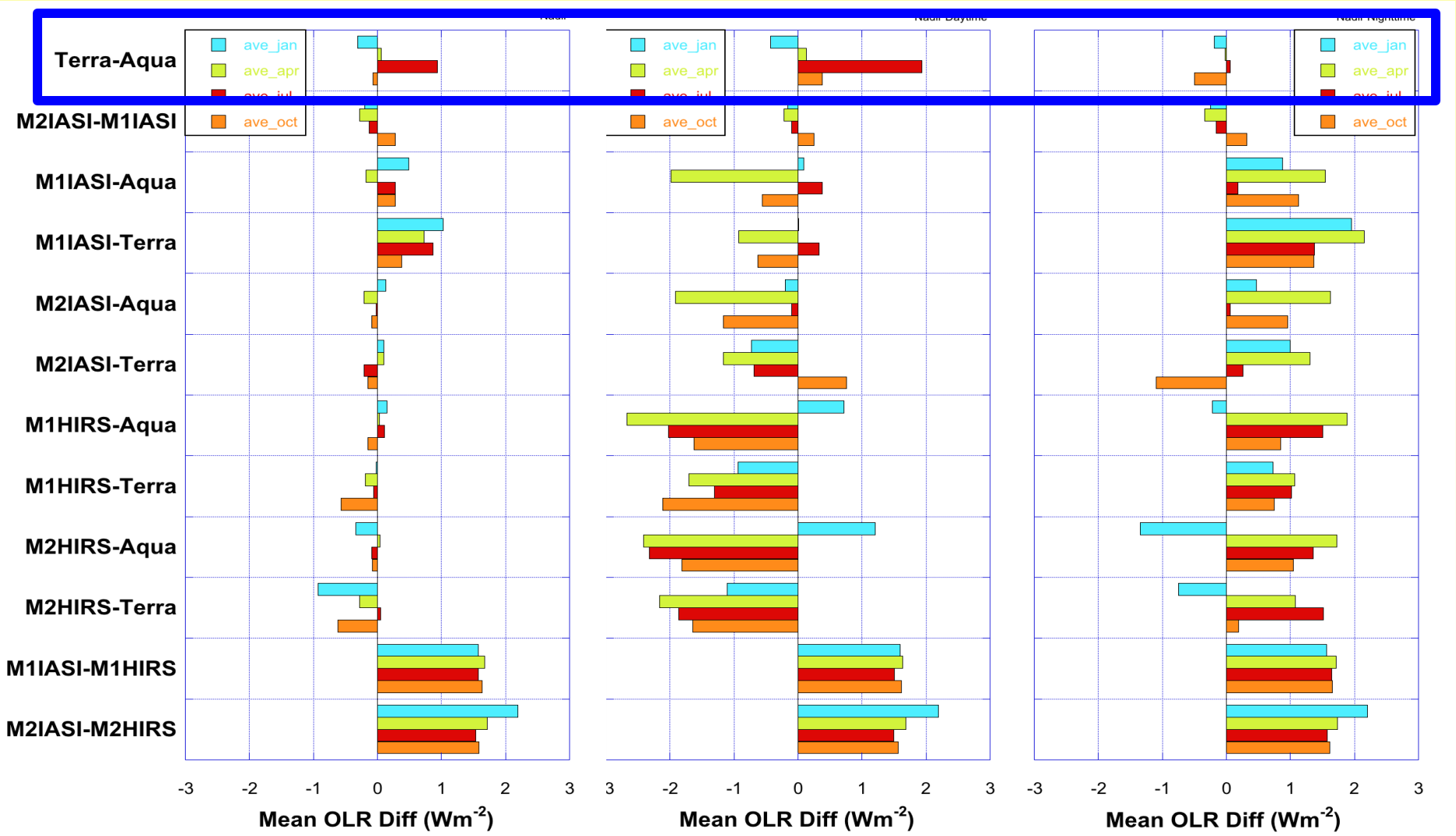
Precision at "Pristine Condition"



- The spread of OLR in 1° circle encompassing target is a metrics for ***Scene Homogeneity*** **– a crucial factor for sampling errors**.
- The STD OLR differences of collocated pairs is subject to the "***Threshold***" of Homogeneity of the scenes.
- The STD OLR difference extrapolated to ***Threshold*****=0** represents the **best estimate of the *Precision at "Pristine Condition".***

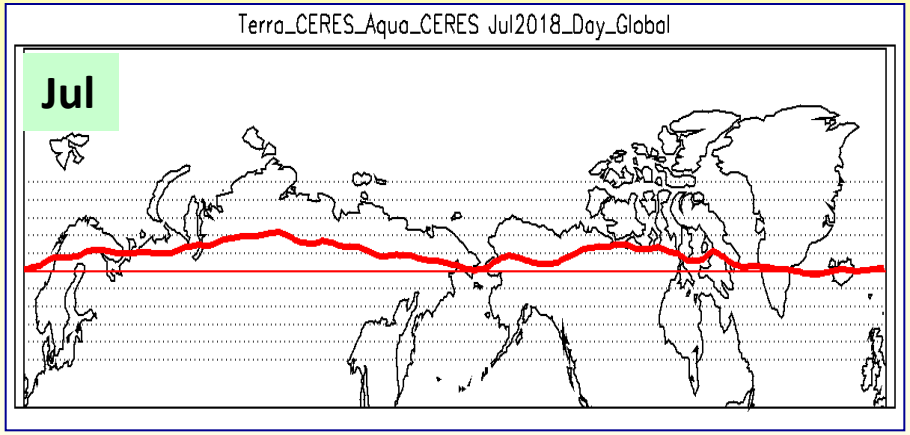
CERES July 2018 Daytime Issues

Nadir

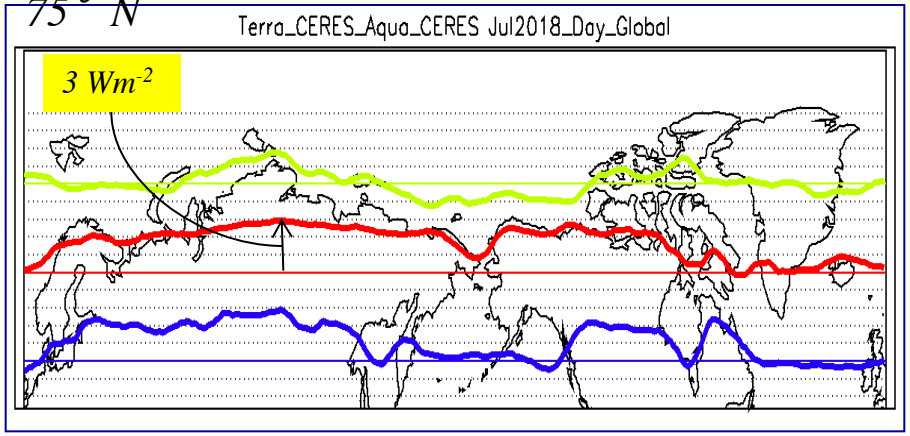

All time
Day
Night
Terra-Aqua
M2IASI-M1IASI
M1IASI-Aqua
M1IASI-Terra
M2IASI-Aqua
M2IASI-Terra
M1HIRS-Aqua
M1HIRS-Terra
M2HIRS-Aqua
M2HIRS-Terra
M1IASI-M1HIRS
M2IASI-M2HIRS
ave_jan
ave_apr
ave_oct
-3
-2
-1
0
1
2
3
Mean OLR Diff (Wm-2)

Terra-Aqua Jul2018 Daytime Issue

All Daytime (mostly N Polar)



Daytime in 10° zones centered at 55°, 65°, 75° N



- Relatively large Terra-Aqua biases were found in Daytime, July 2018.
- The biases occur over land.
  - Mean OLR diff between Terra and Aqua for all Daytime data [top] and for three 10°-zones [bottom] clearly show the biases in tracking with land masses, except Greenland.
- *Pure speculations*:
  - Residual degradation correction error
  - Polar ADM model land/sea differences
  - Snow/Ice map input bug
  - ADM lookup bug

Summary

- ***A new high-precision OLR estimation method for hyperspectral instruments using Spectral Angular Model (SAM) has been developed, with a theoretical accuracy of about 0.2 Wm^{-2}.***
- *Mean OLR differences for IASI-CERES are on par with those within the two CERES (Terra-Aqua), with **relative biases well within ± 1 Wm^{-2}**.*
- *Best estimate of **Precision** (random errors) of instantaneous IASI OLR retrieval is **within 2 Wm^{-2}**, similar to those within CERES.*
- *Terra-Aqua for July 2018 Daytime (N. Polar) show apparent relative biases over land. (reason?)*
- *Slight limb dependence in IASI OLR relative CERES is shown for LZA > 50°.*
  IASI OLR retrieval limb property is considered improved over HIRS, more agreeable with CERES.
- *Future Works*
  - *RTM (LBLRTM) and Cloud properties*
  - *Spectral interval size for SAM*
  - *Scene discretion (Gaussian mixture model)*
  - *Investigate Day/Night differences in limb dependence*

End

Backup Slides

IASI Instrumentation and Data

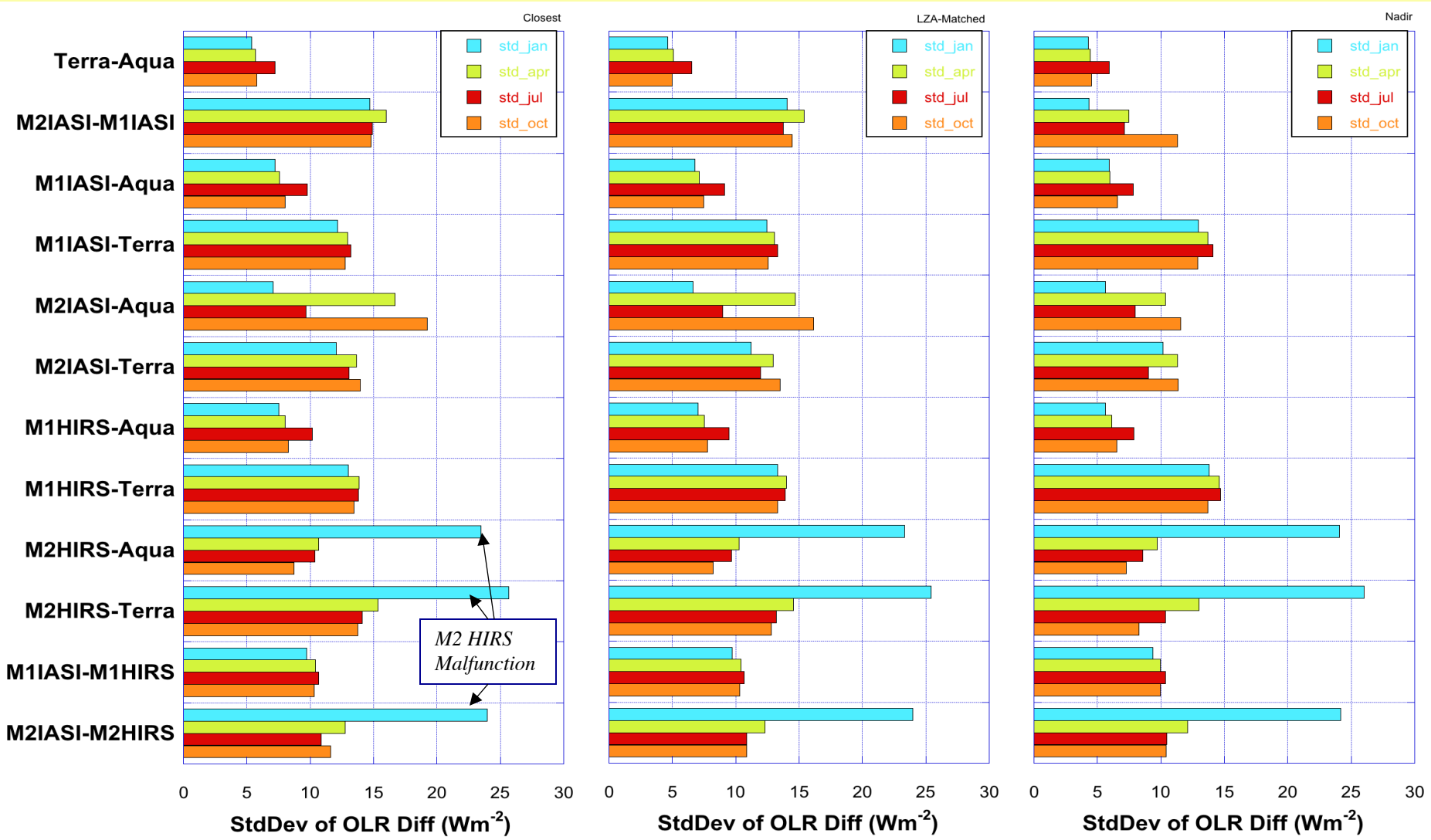
- The *Infrared Atmospheric Sounding Interferometer* (IASI) is composed of a Fourier transform spectrometer and an associated Integrated Imaging Subsystem (IIS)

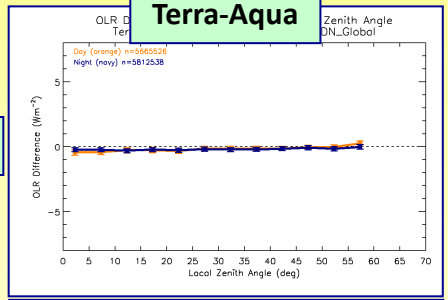
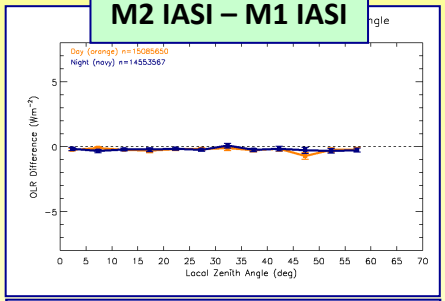
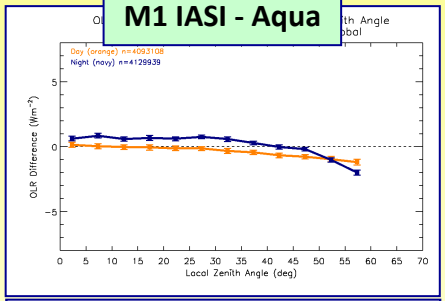
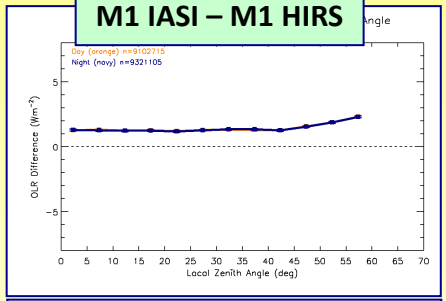
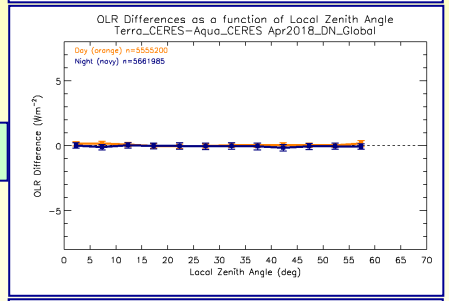
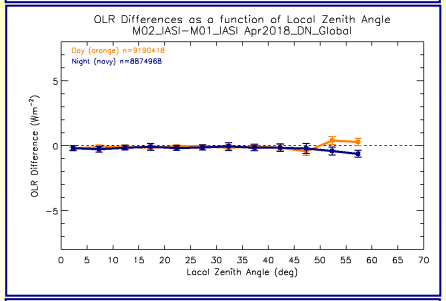
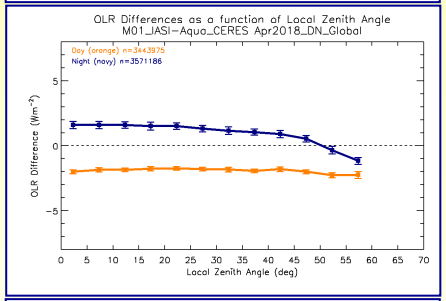
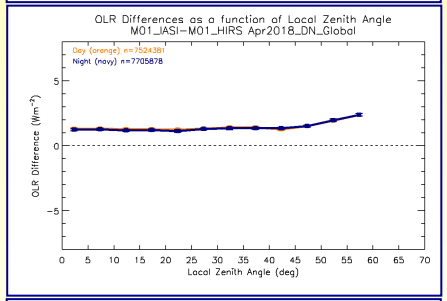
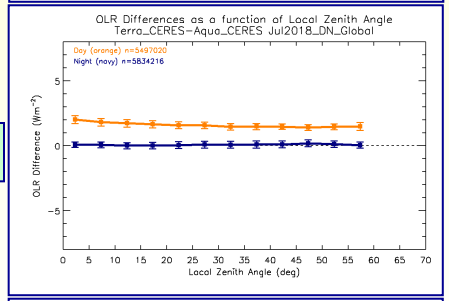
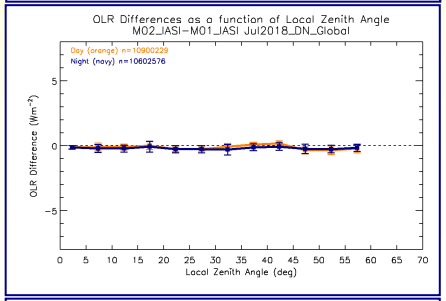
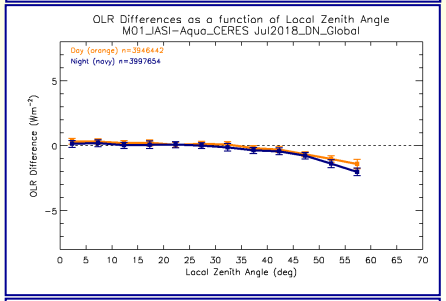
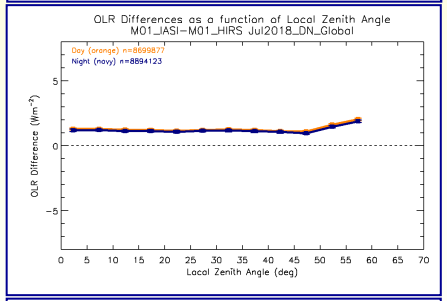
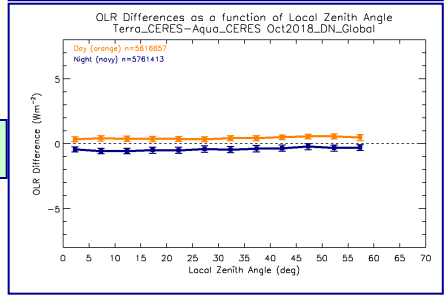
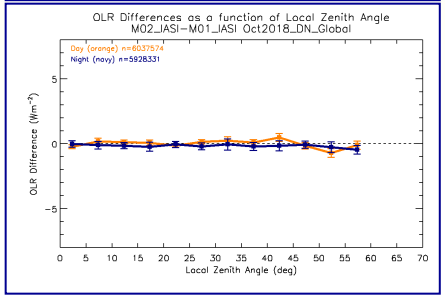
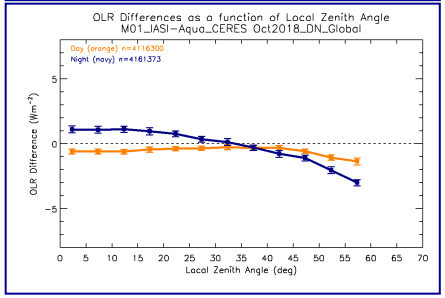
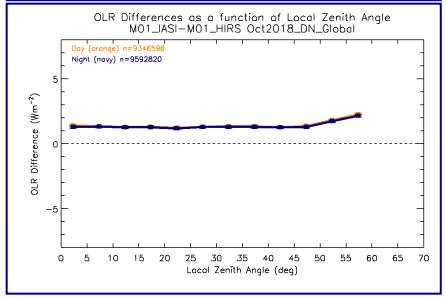
- Three bands between **645 cm^{-1} and 2760 cm^{-1}** (15.5 and 3.63 µm), with a spectral resolution of 0.5 cm^{-1} (FWMH) after apodization (L1C spectra). (the spectral sampling interval is 0.25 cm^{-1})

Band	Wavenumbers (cm^{-1})	Wavelength (µm)
1	645 – 1210	8.26 – 15.50
2	1210 – 2000	5.00 – 8.26
3	2000 – 2760	3.62 – 5.00

- **Level 1C data**: Calibrated apodized radiance spectra with geolocation and time stamp information at the Effective FOV (EFOV) composed of 2x2 Instantaneous FOV (IFOV) at **12 km at nadir**.

All | **LZA-Matched** | **Nadir**



	Terra-Aqua	M2 IASI – M1 IASI	M1 IASI - Aqua	M1 IASI – M1 HIRS
Jan				
Apr				
Jul				
Oct				

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